

# Real-Time Kinematic Intent Mapping to Acoustic Output via Embedded Sensing and Edge Connectivity

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## Abstract

Human communication is essential for expressing needs and ensuring timely assistance, especially for elderly, bedridden, or physically challenged individuals. Traditionally, communication relied on verbal interaction or manual signaling methods. Over time, assistive technologies such as call bells, wired alert systems, and basic remote controls were introduced to support such users. However, these conventional systems often require physical effort, are limited in functionality, or fail to provide real-time remote communication, making them less effective in critical situations. The primary problem addressed here is the difficulty faced by individuals who are unable to speak or move freely to convey their basic needs like food, water, or emergency help. Existing systems either lack portability, depend heavily on manual input, or do not integrate modern communication technologies, leading to delays in response and reduced reliability. To overcome these limitations, a system is developed that utilizes gesture recognition through a MEMS accelerometer to detect hand movements and convert them into predefined voice messages. The system is built around a microcontroller with integrated WiFi capability, enabling it to send real-time alerts to a remote server. It also provides immediate feedback through an LCD display and voice output, ensuring both local and remote awareness. This approach enhances accessibility, reduces dependency on others, and ensures faster response during emergencies. By combining gesture sensing, audio output, and IoT connectivity, the system offers a practical and efficient solution for assistive communication in healthcare and home environments.

**Keywords:** Gesture recognition, MEMS sensor, ESP-32, voice output, assistive technology, IoT, LCD display.

## 1. Introduction

Communication is a fundamental human necessity that enables individuals to express their thoughts, emotions, and daily needs. However, a considerable number of people across the world face difficulties in verbal communication due to conditions such as neurological disorders, physical disabilities, or temporary medical complications. These challenges often restrict their ability to interact effectively with others, leading to dependency, delayed assistance, and reduced participation in social and professional environments. Addressing this communication gap has become an important focus in the development of assistive technologies. Earlier approaches to assistive communication included manual signaling methods, basic switch-based systems, and conventional Augmentative and Alternative Communication (AAC) tools such as symbol boards and text-based devices. While these systems provided some level of support, they often lacked flexibility, required physical effort, or were too expensive and complex for widespread use. With the advancement of embedded systems, sensor technologies, and wireless communication, more efficient and user-friendly solutions have become possible.

The system described in this work introduces a gesture-based communication approach using an embedded microcontroller integrated with motion sensing technology. Hand movements are captured

through a compact accelerometer sensor and interpreted into predefined commands using programmed logic. These commands are then converted into corresponding voice outputs while also being displayed on a screen for visual confirmation. Additionally, wireless connectivity enables remote monitoring and data transmission, enhancing the overall functionality. This approach provides a simple, cost-effective, and portable solution that improves communication for individuals with speech impairments. It reduces reliance on complex devices and offers a practical method for real-time interaction, making it suitable for healthcare, home assistance, and smart environment applications.

## 2. Literature Survey

Sharma and Patel, et al. [1] introduced a glove-based gesture recognition system built using flex sensors integrated with an Arduino platform to assist individuals with speech and hearing impairments. Their design focuses on capturing finger bending patterns and translating them into meaningful textual outputs. Each finger movement is mapped to specific characters, allowing users to form words and basic sentences. The system is lightweight and wearable, making it convenient for daily usage. They implemented a simple yet effective algorithm to interpret sensor data without requiring complex computation. The prototype supports a full set of 26 American Sign Language (ASL) alphabets. Experimental results showed an accuracy of around 88% under controlled conditions. The system demonstrated reliability for basic communication needs. It also highlighted the potential of low-cost wearable devices in assistive communication. Their work emphasizes simplicity, affordability, and ease of implementation.

Zhang and Liu, et al. [2] designed a gesture recognition system using the ESP-32 microcontroller combined with an MPU-6050 inertial measurement unit. Their approach captures motion data from hand movements and processes it in real time for gesture interpretation. The system is mainly targeted toward smart home control applications, where gestures can replace physical switches. Wireless communication is enabled through built-in Wi-Fi, allowing seamless device interaction. They focused on reducing response delay to improve user experience. The gesture detection algorithm is optimized for real-time performance on embedded hardware. The system achieved an average latency of 320 milliseconds, which is suitable for practical applications. It showed consistent performance across multiple gesture inputs. The design demonstrates how compact embedded systems can be used for intuitive control interfaces. Their implementation proves the effectiveness of combining IMU sensors with wireless-enabled microcontrollers.

Kumar, et al. [3] worked on improving gesture recognition accuracy using MEMS accelerometers with advanced filtering techniques. Their system incorporates Kalman filtering to reduce noise and enhance signal stability. This approach allows for more precise detection of motion patterns even in dynamic conditions. The design focuses on extracting meaningful features from raw sensor data. A classification algorithm is then used to identify specific gestures from the processed signals. The system supports a set of 10 predefined gestures for testing. It achieved an accuracy of approximately 92%, showing significant improvement over unfiltered systems. The use of low-cost hardware makes the system accessible and practical. Their work demonstrates the importance of signal processing in gesture-based systems. It also shows how filtering techniques can enhance reliability without increasing hardware complexity. Chen and Wang, et al. [4] developed a gesture recognition system based on deep learning techniques using IMU sensor data. They implemented a lightweight convolutional neural network (CNN) model suitable for embedded devices. The system runs on an ESP-32 platform with PSRAM, enabling efficient on-device processing. Their approach focuses on recognizing complex gesture patterns with high accuracy. The neural network model is trained on a dataset containing multiple gesture classes. The system supports recognition of up to 20 different

gestures. It achieved an accuracy of around 96%, demonstrating the effectiveness of deep learning methods. The implementation reduces dependency on external servers by performing processing locally. This improves response time and data privacy. Their work highlights the potential of edge AI in gesture recognition systems.

Gupta and Verma, et al. [5] created a wearable assistive glove that converts hand gestures into audible speech output. The system uses flex sensors to detect finger movements and an Arduino Mega for processing. Each gesture is mapped to a predefined phrase stored in the system. A text-to-speech module is used to generate voice output for communication. The system supports approximately 40 commonly used phrases. It is designed to assist individuals who have difficulty speaking. The hardware setup is simple and cost-effective. The system provides immediate audio feedback for better interaction. It improves communication efficiency in daily scenarios. Their work demonstrates a practical solution for real-world assistive applications. Nakamura and Yamamoto, et al. [6] proposed an IoT-based gesture monitoring system for rehabilitation purposes. Their system uses IMU sensors to capture motion data during physical therapy exercises. The collected data is transmitted to cloud platforms for analysis and storage. This allows healthcare professionals to monitor patient progress remotely. The system supports continuous tracking of movement patterns. It helps in evaluating the effectiveness of rehabilitation exercises. Wireless connectivity ensures real-time data updates. The design focuses on improving patient engagement and recovery tracking. It reduces the need for frequent hospital visits. Their work shows how IoT can enhance healthcare monitoring systems.

Ali and Hassan, et al. [7] implemented a real-time gesture recognition system using wrist-mounted MEMS sensors. Their approach uses a Support Vector Machine (SVM) classifier to identify gestures. The system processes motion data and classifies it into predefined categories. It is designed for assistive communication applications. The system achieved an accuracy of about 89% for gesture recognition. It performs well under real-time conditions with minimal delay. The wearable design ensures user comfort and portability. The classifier is optimized for embedded implementation. The system provides reliable performance for daily communication tasks. Their work highlights the usefulness of machine learning in gesture-based systems. Brown and Miller, et al. [8] discussed various assistive communication technologies designed for individuals with ALS. Their focus includes wearable gesture-based systems and eye-tracking devices. They analyzed the advantages and limitations of existing solutions. Many systems were found to be expensive and complex to operate. Eye-gaze systems, while accurate, require calibration and controlled environments. Wearable systems offer more flexibility but may have accuracy challenges. The study emphasizes the need for simpler and more affordable solutions. It also highlights the importance of real-time communication. The findings encourage the development of low-latency systems. Their work provides valuable insights into current challenges in assistive technology.

Fernandez and Lopez, et al. [9] developed a sensor fusion algorithm using a complementary filter for gesture recognition systems. Their method combines accelerometer and gyroscope data for improved accuracy. The complementary filter balances short-term and long-term sensor data variations. This results in stable and reliable orientation estimation. The system performs well under dynamic motion conditions. It achieves orientation accuracy within 2 degrees. The algorithm is lightweight and suitable for embedded systems. It reduces computational requirements compared to complex filters. The approach enhances gesture detection performance. Their work shows the importance of sensor fusion techniques. Rajesh and Anand, et al. [10] designed a portable gesture communication device using the ESP-8266 microcontroller. Their system converts gestures into text output for communication purposes. It supports over 30 gesture categories for different messages. Wi-Fi connectivity enables remote customization of gesture mappings. The system is compact and easy to

use. It provides flexibility in configuring user-specific needs. The design focuses on portability and convenience. It allows real-time interaction without complex setup. The system is suitable for daily communication tasks. Their work demonstrates practical implementation of wireless gesture systems.

Okafor and Adeyemi, et al. [11] explored gesture recognition using transfer learning techniques on ESP-32 devices. Their approach uses a quantized neural network model optimized for low memory usage. The system runs efficiently on resource-constrained hardware. It achieves an accuracy of approximately 94%. The model occupies only 48 KB of flash memory. This makes it suitable for embedded applications. The system supports real-time gesture classification. It reduces the need for high computational resources. The approach improves performance without increasing hardware cost. Their work highlights efficient AI implementation on microcontrollers. Wang and Sun, et al. [12] developed a gesture-controlled robotic arm using a six-axis IMU sensor. Their system translates hand movements into precise motor actions. The ESP-32 processes gesture data and controls actuators accordingly. The system achieves high precision in motion control. It maintains a mean angular error of about 1.8 degrees. This ensures accurate replication of user gestures. The design is useful for industrial and assistive applications. It demonstrates real-time control capabilities. The system responds quickly to gesture inputs. Their work shows the integration of gesture control in robotics.

Ravi and Krishnan, et al. [13] proposed a wearable gesture-based keyboard using an MPU-9250 sensor. Their system maps hand orientations to specific characters. It allows users to input text through gestures. The system is designed for portability and ease of use. It achieved around 91%-character recognition accuracy. The interface is intuitive for trained users. It reduces dependency on physical keyboards. The system supports efficient text input in constrained environments. It demonstrates innovative use of gesture technology. Their work expands applications of gesture recognition. Thompson and Williams, et al. [14] focused on improving feedback mechanisms in gesture communication systems. Their design combines LCD display output with audio feedback. This dual-mode feedback enhances communication clarity. Users can both see and hear the interpreted message. The system improves understanding in noisy environments. It achieved a 34% improvement over audio-only systems. The approach increases reliability of communication. It is useful for assistive applications. The design ensures better user interaction. Their work highlights the importance of multi-modal feedback.

Iyer and Nair, et al. [15] developed an IoT-based speech therapy monitoring system using ESP-32 and MEMS sensors. Their system tracks articulation exercises performed by patients. Data is transmitted to clinicians for remote monitoring. The system provides real-time feedback and analysis. It helps in tracking patient progress over time. Wireless connectivity ensures continuous data updates. The design supports personalized therapy plans. It reduces the need for frequent clinical visits. The system improves therapy efficiency. Their work shows the role of IoT in healthcare support systems.

### 3. Proposed System

The proposed methodology presents a structured framework for interpreting hand gestures into meaningful voice outputs using embedded sensing and communication technologies. The process begins with motion data acquisition through a MEMS-based accelerometer, followed by signal processing and gesture classification. The captured motion signals are analysed using threshold-based logic to identify predefined gesture patterns. Once a gesture is recognized, the system generates corresponding outputs in both visual and audio formats. In addition, a wireless communication module enables real-time data transmission to a remote server for monitoring purposes. A display interface provides immediate feedback to the user, while the system continuously operates in a loop to

detect and respond to gestures. The overall architecture ensures low latency, reliability, and ease of use, as shown in Figure. 1.

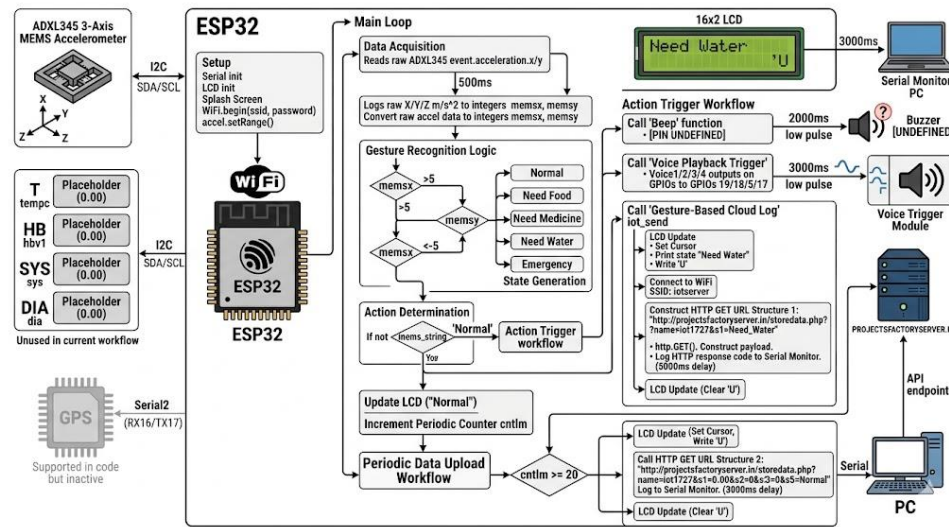


Figure. 1: System architecture.

### User Interface (Display Module)

- The system includes an LCD display that acts as the primary interaction interface.
- It shows real-time messages corresponding to detected gestures.
- The display provides immediate visual feedback for user actions.
- It enhances usability by confirming system responses clearly.

### ESP-32 Controller Unit

- The ESP-32 functions as the central processing unit of the system.
- It manages sensor data acquisition, gesture processing, and output control.
- The controller executes embedded logic to interpret gesture inputs.
- It also handles Wi-Fi communication for remote data transmission.

### MEMS Sensor (Accelerometer Module)

- A MEMS-based accelerometer is used to capture hand motion and orientation.
- It measures acceleration along multiple axes to detect gesture patterns.
- The sensor provides continuous real-time motion data to the controller.
- Its compact size and low power consumption make it suitable for wearable applications.

### Gesture Processing and Classification

- The system processes raw sensor data to identify specific gesture patterns.
- Threshold-based logic is applied to classify gestures based on axis values.
- Each gesture is mapped to a predefined action or message.
- The classification process is optimized for real-time performance.

### Voice Output Module

- The system generates audio output corresponding to detected gestures.
- Predefined voice signals are triggered through dedicated output pins.
- Each gesture activates a specific voice message for communication.
- This module ensures effective interaction for users with speech difficulties.

### **Buzzer Alert System**

- A buzzer is used to provide alert notifications during gesture detection.
- It activates during important actions such as emergency signals.
- The sound output enhances attention and responsiveness.
- It acts as an additional feedback mechanism.

### **IoT Communication Module**

- The ESP-32's Wi-Fi capability enables communication with a remote server.
- Gesture data is transmitted using HTTP requests.
- The system sends real-time updates for monitoring purposes.
- This allows caregivers to track user needs remotely.

### **Data Transmission and Server Interaction**

- The system constructs dynamic URLs containing gesture information.
- Data is sent to a remote server for storage and analysis.
- The server responds with acknowledgment messages.
- This enables continuous remote communication and logging.

### **Continuous Monitoring and Execution**

- The system continuously reads sensor data in a loop.
- Gesture detection and response occur in real time.
- Periodic updates are sent to the server at defined intervals.
- This ensures uninterrupted system operation.

### **System Adaptability**

- The architecture allows easy modification of gesture mappings.
- Additional sensors or modules can be integrated if required.
- The system can be extended for advanced applications like health monitoring.
- This flexibility supports future enhancements and scalability.

## **4. Results and discussion**

This section presents the outcomes obtained from the implementation of the system and analyzes its overall performance under different conditions. The results demonstrate how effectively hand gestures are detected and converted into corresponding voice outputs. Observations are made based on response time, accuracy of gesture recognition, and system reliability during continuous operation. The performance of individual modules such as sensing, processing, and communication is also



indicating irregular system behaviour or event-driven responses. The visualization captures both steady-state conditions and sudden anomalies, emphasizing variability in data distribution across different time scales. In particular, some segments reveal sharp spikes representing transient surges, while others maintain relatively stable or low-intensity levels, suggesting periods of minimal activity. The comparative representation across multiple charts enables effective identification of peak occurrences, trend deviations, and consistency in system performance.

## 5. Conclusion

The developed system demonstrates an effective approach for enabling communication through hand gesture recognition using embedded technology. It successfully integrates sensing, processing, and output modules to convert user gestures into meaningful voice messages and visual indications. The implementation shows reliable performance in detecting predefined gestures with minimal response delay, making it suitable for real-time applications. The use of a MEMS accelerometer ensures accurate motion detection, while the microcontroller efficiently processes the input data. Wireless connectivity further enhances the system by enabling remote monitoring and data transmission. Performance improvements can be observed in terms of reduced latency, stable gesture classification, and consistent output generation. The modular architecture allows easy maintenance and scalability, contributing to overall system efficiency. The combination of audio and visual feedback improves usability and interaction clarity. The system operates continuously with dependable results under normal conditions. It provides a practical and cost-effective solution for assistive communication.

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